MAPPER: A Software Program for Image Quantitative Characterization

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Abstract

General images and signals are texturally complex and heterogeneous. In order to parse such images and signals into distinct regions of interest, one traditionally has relied largely on qualitative verbal and/or visual descriptive methods. This has limited the ability to robustly automate the segmentation process. For this reason, increasing attention is being paid to quantification of the past verbal and visual descriptive methods. In this light, the efforts surrounding the numerically quantification of fractal textures has shown great promise. Mandelbrot theorized that a fractal could be fully quantified via three base quantities: fractal dimension, lacunarity, and what we call connectivity. In this work we focus on the first two quantities fractal dimension and lacunraity. In order to allow for an easy automated method to evaluate the parsing ability of said statistics; a software program entitled MAPPER was developed to generate a topographical color map overlay of the sub-regions on a baseline gray scale image. Textural changes can be clearly defined through the color changes in the topographical map overlays. In order to speed the quantification process, the software program was designed for a distributed architecture using multiple hardware and system configurations via a secure network protocol. Our program achieves a near one to one processor scale speed increase with each additional node added to a mixed network of x86 Linux, Alpha Linux, and PPC MacOS X computers running OpenSSH, for each sub-region defined within the original image. No special network or hardware is required such as a Beowulf computer (we can, however, take advantage of Beowulf hardware). The software's GUI was implemented in TCL/TK and is portable to all major operating systems that have an implementation of TCL/TK, OpenSSH, and GNU gcc (this includes Linux, Unix, MacOS X, and Windows). The software program was originally developed as a diagnostic tool for assessing the mechanisms of biofilm structure and has been evaluated using microscopic biofilms and synthetic biofilm images as well as the more traditional target detection images shown throughout this document.

Quantifying image textures

Signals and images can be quantified using a variety of statistics. One such statistic commonly used is the fractal dimension. However, fractal dimension provides an incomplete description of the texture content of said signals (i.e. it is well known that two images can have same fractal dimension but look markedly different, see the reverse side). Another independent statistic though directly related to fractal dimension is lacunarity. In the past this has been employed as a second order statistic. As a second order statistic, it has remained largely ignored, however this designation is primarily due to the lack of a viable definition of lacunarity. Recently, we have developed several new ways to define and measure lacunarity based on its Latin root of the word--Lacuna meaning gap. These new definitions overcome problems associated with the common lacunarity measure, glide box, namely their strong correlation to the fractal dimension itself. More details on our fractal dimension and lacunarity definitions are given on the reverse side.

Topographical "Mapping" of an image

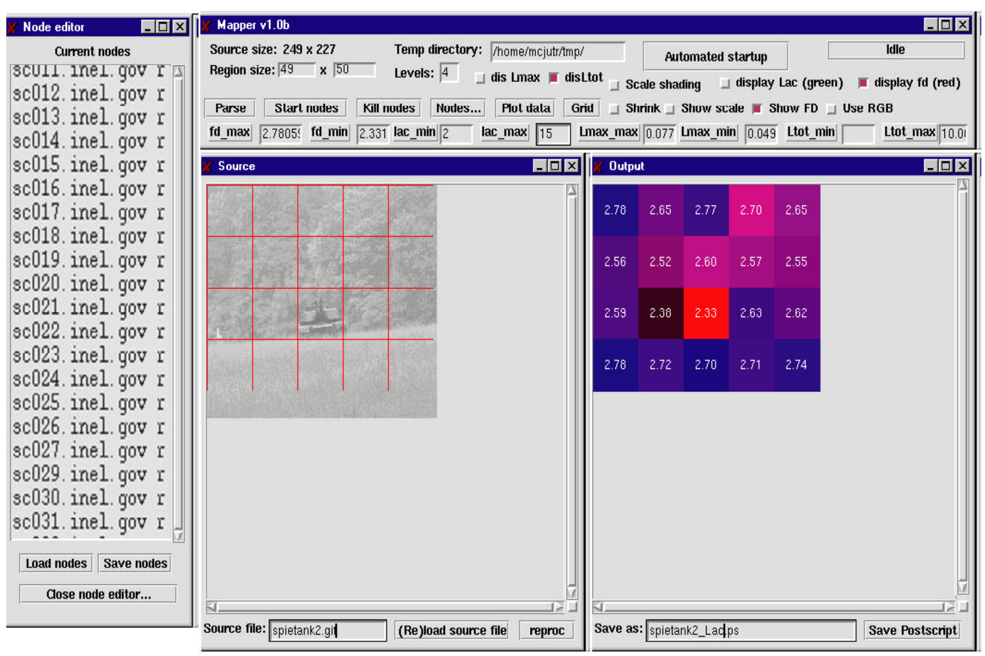
In an image, like the one shown and analyzed in this paper, we would like to parse/segment the image into distinct textural regions. The approach taken here is to divide the image into rectangular regions and characterize each region with fractal dimension and lacunarity parameters. These statistical parameters form an algorithm method for parsing the image in to dissimilar textural regions. This is the first step needed within the object recognition and target detection problem.

The parameters are represented in RGB composite overlays of Red (for either lacunarity maximum of the minimum spanning tree, or the total span of that tree), Green (for lacunarity Musgrave parameter), and Blue (for fractal dimension). The result of this mapping is shown in the composite RGB image overlaid on the biofilm.

"Mapper" is a TCL/TK user interface built for controlling the segmenting and processing of images over a distributed cluster of computers. The user has control of how the image is segmented and defines any necessary parameters for the processing program. The program copies all necessary scripts and binaries to each of the nodes using the preferred secure shell (ssh) or remote shell (rsh).

Mapper launches a client script on each node which waits for an assignment. Mapper creates a file for each node with the filename of the image segment assignment. When done processing the segment the client copies the results back to the host node and receives another assignment if there are remaining segments. Mapper then displays the results in the interface.

This remarkably efficient method of achieving massive parallelism in processing large images, provides near one to one scaling with each additional processor.



Mapper graphical user interface

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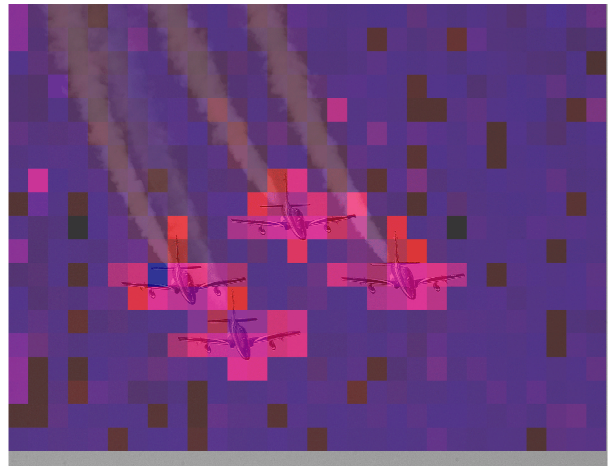
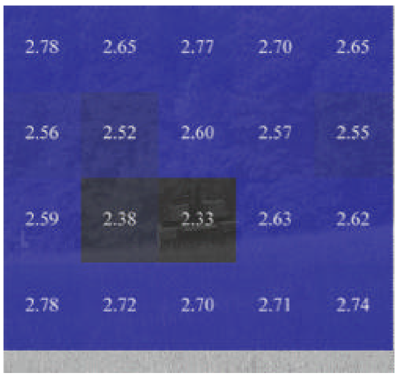
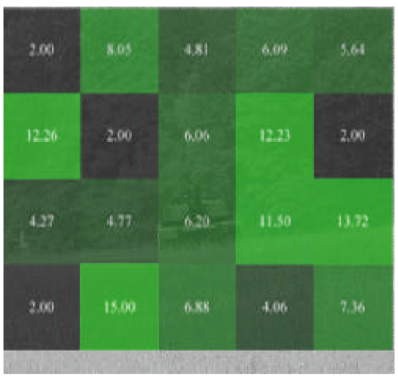
Image to be parsed into texturally defined regions.

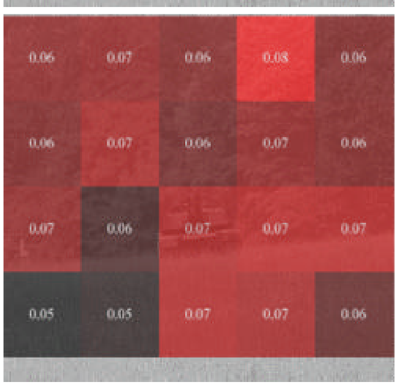
Composite overlay of fractal dimension and lacunarity parameters. Note the superior parsing affects that have been achieved via the combined overlay, i.e. each region, namely tank, grass, and trees, exhibit their own distinct color.

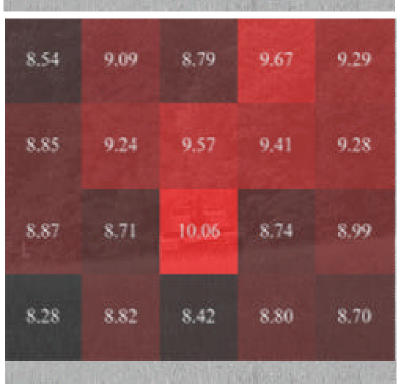


Composite overlay analysis of aircraft squadron, fractal dimension (blue), and L_max lacunarity (red). Notice that both the aircraft and contrails standout form the background.







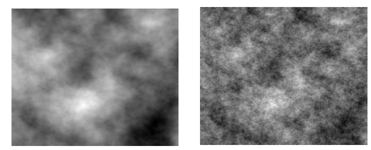


Fractal Dimension

Fractal Dimension (FD) is a measure of how much space is filled in a signal or image. The simplest example of a set with a specific fractal dimension is the Cantor dust, where each subsegment is made up of a scaled copy of the previous scale. The diagram at the right shows the construction of a Cantor set where the scaling factor is 3 and 2 copies of each scale are made at each successive level. FD = Log(2)/Log(3) using the similarity dimension.

Our highly accurate estimator of FD for images uses fuzzy-c means clustering to find the slope of the log of the size of the cluster vs. the log of the number of clusters, e.g. an approximation the Hausdorff FD measure. Images to the right show textures on which our algorithm was validated.

Cantor Dust Construction



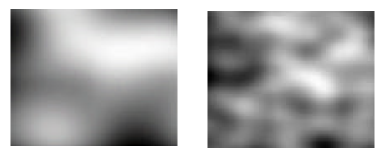
FD = 2.1 FD = 2.7

Brownian Random Fractal Textures

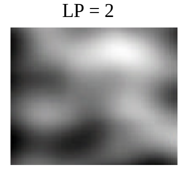
Lacunarity (Dense/Image Data)

Musgrave's Brownian random fractal texture generating algorithm shows that there is another parameter which can effect the look of a texture. To the right are 3 more textures (limited to 2 self similar scales) with various Lacunarity parameters (LP).

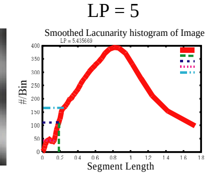
We developed another algorithm that uses the same clustering methods as our FD estimator for approximating Musgrave's parameter. This method creates a histogram of the length of line segments connecting two cluster which do not pierce any other cluster. The reciprocal of the midpoint of the steepest slope gives us the parameter. The graph at the right shows an example of the histogram and parameter estimation.



LP = 2 LP = 5

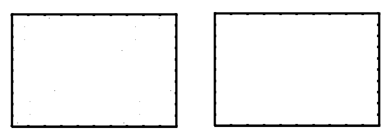


LP = 3



Lacunarity (Max Span - Lmax)

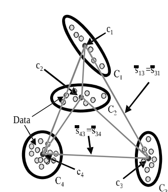
Ramified data sets can also be quantified with Fractal Dimension measures; here again, two sets with similar FD can have very different forms. To the right are 2D Cantor Dusts which have the same FD but a different look. Lmax and Ltot Lacunarity measures have the capability to distinguish between these sets. The graphics below to the right show the formation of the minimum spanning tree. Lmax is the length of the longest span in this tree. This measure was not originally thought to be useful in analyzing images; however, it does appear to help distinguish between different types of image textures.



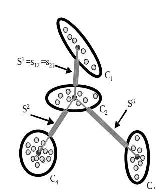
2D Cantor Dusts fixed FD with differing Lacunarities

Lacunarity (Total Span - Ltot)

Ltot is the sum of the lengths of the segments of the minimum spanning tree. This measure, although also designed for ramified data has been somewhat useful with images.



Clusters and all spanning segments



Minimum spanning tree

References

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2. C.R. Tolle, T.R. McJunkin, D.T. Rohrbaugh, R.A. Laviolette, *Optimal-cover based definitions of lacunarity for ramified data sets*. submitted for review to Physica-D 2002.

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